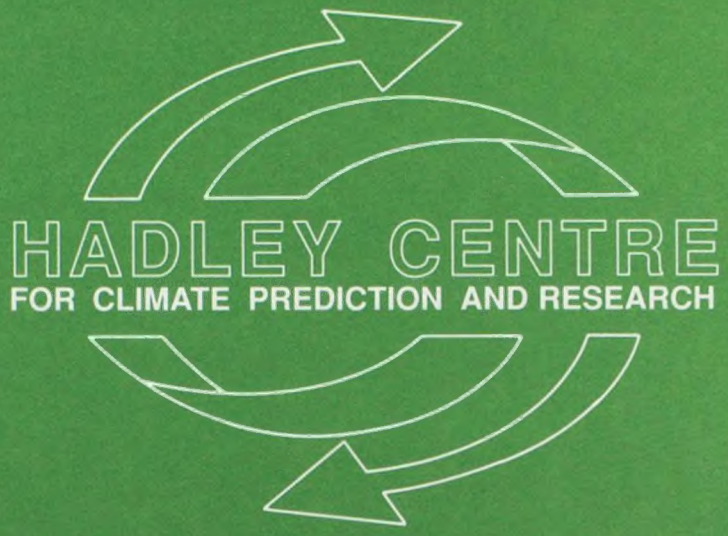

Low frequency variability of the Oceans

by

C. K. Folland, A.Colman, D. E. Parker, A. Bevan

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Invited paper at the WMO Training Workshop on Diagnostics and Prediction of Monthly and Seasonal Atmospheric Variations, Nanjing, China, 8-19 October 1990.

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LOW FREQUENCY VARIABILITY OF THE OCEANS

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Considerable progress has recently been made in creating and analysing sea surface and near surface air temperature data over the oceans. The first analyses of trends in deep ocean temperatures have also been published and new insights are starting to emerge concerning the mechanisms of low frequency oceanic variability. Recent studies of the low frequency variations of ocean and land surface temperatures are reviewed in section 7 of IPCC (1990), on which this short paper is partly based.

1. Ocean and land surface temperature

Fig. 1, taken from IPCC (1990), shows some of the presently best available estimates of decadal and longer time scale global mean ocean surface and land temperature variations since 1861.

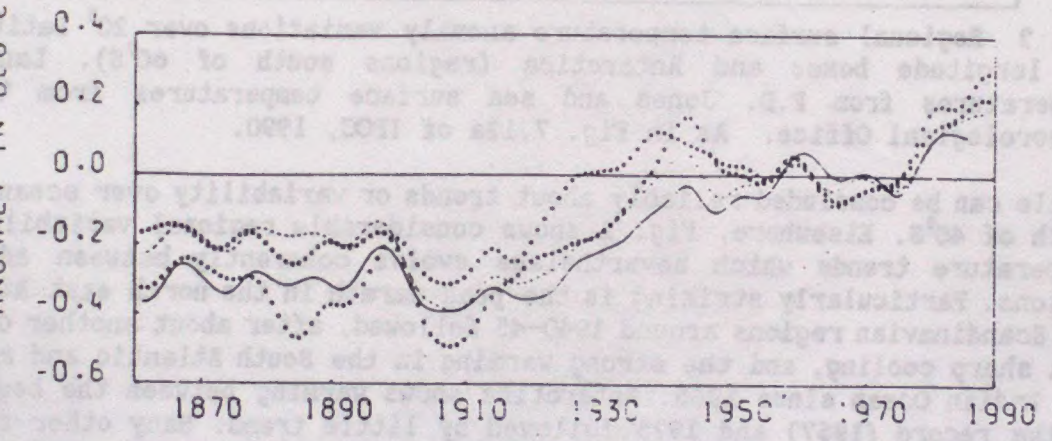


Fig. 1 Global sea surface, night marine air (crosses) and land air temperature anomalies (dots) 1861-1989, relative to 1951-80. SST values are taken from Farmer et al. (1989) (solid line) and the UK Meteorological Office (dashed line). Night marine air temperatures from UK Meteorological Office. Land air temperatures are equally weighted averages of data from Jones (1988, updated), Hansen and Lebedeff (1988), and Vinnikov et al (1990). The curves are based on annual data smoothed with a 21 term binomial filter designed to suppress fluctuations on less than about a decade.

Over the last century, variations of corrected global night-time marine air temperature have been quite similar to those of SST. A minimum of temperature around 1910 is clearly visible, especially in the ocean data. The data sets also agree on a relatively sharp rise of temperature between about 1920 and the early 1940s followed by a pause. Since about 1975 there has been a renewed temperature rise. (It now seems (late Sept 1990) that 1990 will be distinctly warmer, globally, than the average of the 1980s). SST and night marine air temperature data appear to lag the land data by at least five years during the period of warming that commenced around 1920. However some of the additional warmth of the land at this time may be erroneous due to the use of thatched open shed screens in parts of in the tropics (Field, 1920). The probable small global impact of urbanisation on the land record is discussed in Jones et al (1990) while the complex corrections applied to marine, especially SST, data before the mid 1940s are discussed in Folland and Parker (1990) and Farmer et al (1989). Significant disagreements concerning the level of global mean SST anomalies in the nineteenth century is shown by the two analyses in Fig. 1.

This can be traced to different opinions on how these early data should best be corrected for their biases.

The reality of the century time scale trends in Fig. 1 is supported by a clear, if unsteady, worldwide recession of mountain glacier termini since the late nineteenth century (Grove, 1988; IPCC, 1990).

Fig. 2 gives more detail of regional low frequency variations of combined land surface air temperature and SST on a 60° longitude x 20° latitude space scale (Fig. 7.12a of IPCC, 1990).

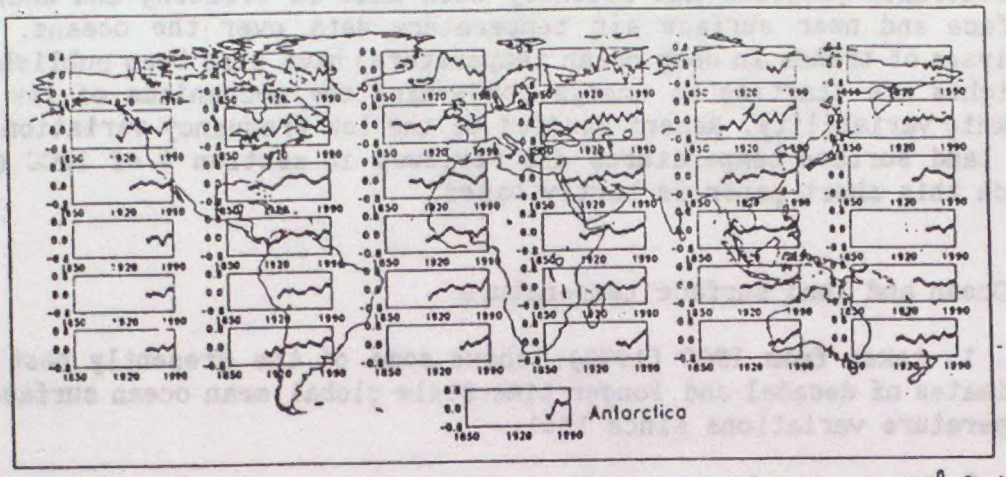


Fig. 2 Regional surface temperature anomaly variations over 20° latitude x 60° longitude boxes and Antarctica (regions south of 60°S). Land air temperatures from P.D. Jones and sea surface temperatures from the UK Meteorological Office. As in Fig. 7.12a of IPCC, 1990.

Little can be concluded reliably about trends or variability over ocean areas south of 40°S. Elsewhere, Fig. 2 shows considerable regional variability in temperature trends which nevertheless evolve coherently between adjacent regions. Particularly striking is the peak warmth in the north east Atlantic and Scandinavian regions around 1940-45 followed, after about another decade, by a sharp cooling, and the strong warming in the South Atlantic and much of the Indian Ocean since 1965. Antarctica shows warming between the beginning of the record (1957) and 1975 followed by little trend. Many other regions show intermediate patterns indicating that regional temperature trends over both land and ocean can, and do, vary considerably from the pattern of the global average. Note that the smoothing used (the same as in Fig. 1) filters out ENSO time-scale influences.

Fig. 3 shows zonally-averaged land air temperature and SST anomalies using the same data as in Fig. 2. Almost uniformly cooler conditions in the nineteenth century are seen in all zones, extending into the early twentieth century. Warming around 1920-1940 occurs in most zones, except perhaps over northern regions of the Southern Ocean, with a strong warming, exceeding 0.8°C, occurring to the north of 60°N over this period.

Cooling after 1950 was mainly confined to the Northern Hemisphere, though weak cooling is evident in the Southern Hemisphere tropics between about 1940 and the early 1950s. Clear signs of renewed warming in most Southern Hemisphere zones exist before 1970 which continued until the early 1980s and more slowly thereafter. Over Antarctica some warming is seen near the coast but inland there has been little change. Renewed warming is seen in the Northern Hemisphere in all zones after the early 1970s, including small rises in high latitudes, a fact hitherto little appreciated. The marked cooling in the Atlantic/Barents Sea sector in recent decades (Fig. 2) is not clearly seen elsewhere in high latitudes, though even this cooling seems to have ceased or reversed since 1985.

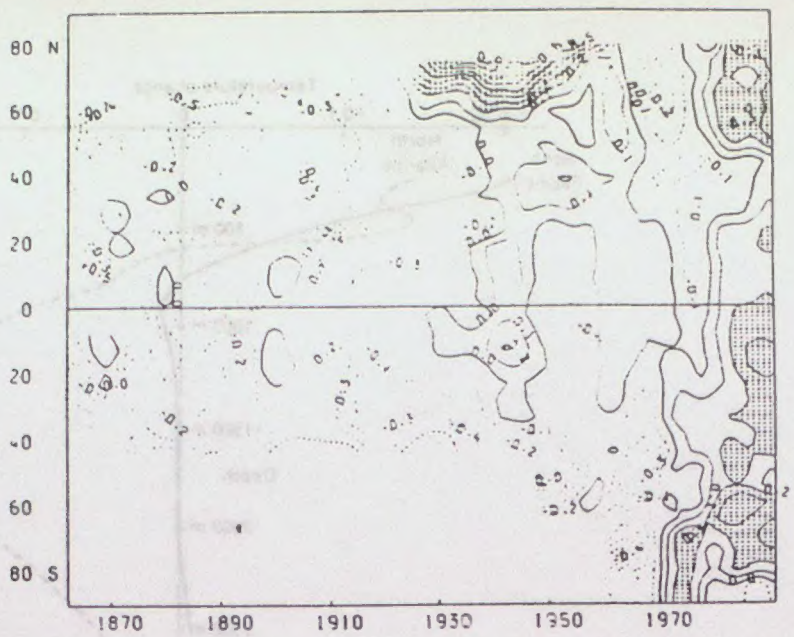


Fig 3. Zonal averages of combined sea surface and land data, 1861-1989. Land air temperatures from P.D. Jones and sea surface temperatures from the UK Meteorological Office. Improved version of Fig. 7.12 of IPCC, 1990.

2. Sub-surface ocean temperature.

Levitus (1989, and other papers referred there) has carried out a major study of changes of sub-surface temperature and salinity of the North Atlantic Ocean between 1955-59 and 1970-74. 1955-59 was near the end of a very warm period of North Atlantic surface waters, but by 1970-74 the subsequent cool period was well developed (Fig. 2). Cooler water extended from near the sea surface to 1400m depth in the subtropical gyre (30-50^{0}N). Beneath the subtropical gyre, a warming occurred between the two periods. North of this gyre there was an increase in the temperature and salinity of the western sub-arctic gyre. The density changes associated with these changes in temperature and salinity indicate that the transport of the Gulf Stream may have decreased between 1955-59 and 1970-74.

Antonov (1990) has carried out a complementary study for the North Atlantic and North Pacific. He finds that zonal averages of temperature differences between 1957 and 1981 show statistically significant cooling in the upper layers and a warming in the deeper layers of the North Atlantic below 600m when averaged over the North Atlantic as a whole. This agrees well with Levitus' results for the North Atlantic. Basin mean temperature changes (1957-1981) for the North Atlantic and North Pacific, as computed by Antonov, are shown in Fig. 4.

Complementary fluctuations in ice cover have also been noted in the North Atlantic (Mysak, 1990). The reasons for some of the changes are partially understood. For example, the cooling of the upper 1400m of the subtropical gyre was due to an upward displacement of cooler, fresher water. Why this displacement occurred is not definitely known, but may be related to changes in the large-scale wind field over the North Atlantic (Newell and Hsiung, 1987). Of particular importance is the temperature increase of approximately 0.1^{0}C over, on average, a thousand metre thick layer in the deep North Atlantic because it represents a relatively large heat storage. Even the upper few metres of the ocean can store as much heat as the entire overlying atmospheric column of air. The magnitude and extent of the observed changes in the temperature and salinity of the deep North Atlantic are large enough that they cannot be neglected in future theories of climate variations.

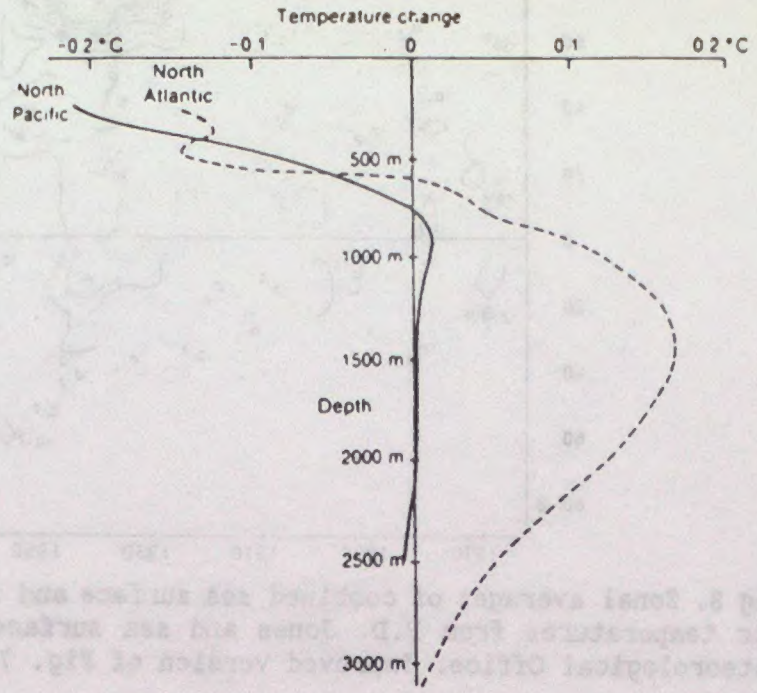


Fig. 4 Sub-surface ocean temperature changes at depth between 1957 and 1981 in the North Atlantic and North Pacific. Adapted from Antonov (1990).

3. Eigenvector analyses of surface marine temperature

Eigenvector (EOF) analysis is a useful method of searching for the most prominent underlying patterns of variation that contribute to Figs 1-3. Here we consider only global-scale analyses of the ocean. Figure 5 shows the first 3 covariance EOFs of annual SST anomalies (from a 1951-80 average) calculated for 1900-1989, together with their time series (EOF time coefficients) plotted seasonally in various ways. The EOFs are based on data distributed over quasi-uniform grid boxes of size approximately equal to that of a 10^0 latitude x 15^0 longitude box centered on the equator. Table 1 shows the percentage (P) of annual variance explained by the first three annual EOFs of both SST and NMAT and by the first all (three month) seasons EOFs of SST and NMAT. Correspondingly numbered annual and all seasons SST and NMAT EOFs have fairly similar patterns.

Fig. 5a shows that annual SST EOF1 has almost uniformly positive signs over the globe while annual SST EOF2 (Fig. 5b) has the pattern of El Nino in the Pacific, including the cooler/warmer waters in parts of the extratropical north and South Pacific commonly associated with warm/cool water in the tropical central and east Pacific. Annual SST EOF3 (Fig. 5c) reflects a quasi-interhemispheric contrast of anomalies but with the north and south Indian oceans having mostly the same sign.

TABLE 1 EIGENVECTORS OF SST AND NMAT FOR 1900-1989 BASED ON A QUASI-UNIFORM GRID

	ANNUAL SST		ANNUAL NMAT		ALL SEASONS SST		ALL SEASONS NMAT	
	P	r	P	r	P	r	P	r
EOF1	24.2	.95	21.8	.95	14.5	.88	11.6	.92
EOF2	15.5	.77	12.3	.73	10.2	.57	7.4	.59
EOF3 (a)	6.2	.58	7.0	.49	4.0	.54	4.0	.46
(b)		.59		.44		.59		.43

Similar EOF patterns were calculated by Folland and Colman (1988) using (variable area) 10^0 box data from all four seasons over 1901-80. Note the substantially smaller proportion of seasonal variance accounted for by the seasonal EOFs in Table 1 when compared with the proportion of annual variance accounted for by the annual EOFs.

Table 1 and fig. 5 also show the high correlation (r) between annual and all seasons SST EOF1 coefficients with global mean SST over 1901-89, where both are calculated on a seasonal time scale. There is also a high correlation of NMAT annual and all seasons EOF1 with global NMAT. SST and NMAT EOFs 2 have also show good correlations with seasonal SST in a region representative of El Nino warming and cooling in the tropical Pacific (160^0-75^0W, 20^0N-5^0S). Annual SST and NMAT EOFs 3 show correlations of near 0.6 with Nicholson's annual Sahel rainfall index (updated to 1989) for (a) coefficients measured in April-June (b) in July-Sept. Fig. 6 illustrates the corresponding pairs of time series for annual NMAT EOFs 2 and 3. It can be seen that the correlations of annual NMAT EOF3 with Sahel rainfall are largely, but not wholly, on a decadal time scale. Folland et al. (1991) illustrate this using cross spectral techniques and all seasons SST EOFs based on 10^0 boxes and 1901-80 data.

Conclusions

Important low frequency variations of the ocean clearly exist. Together with the increasing likelihood of climatic change more directly attributable to an increase in the concentration of greenhouse gases, this implies that decadal and longer time-scale variability cannot in future be neglected in long-range forecasting, especially on seasonal and longer time scales.

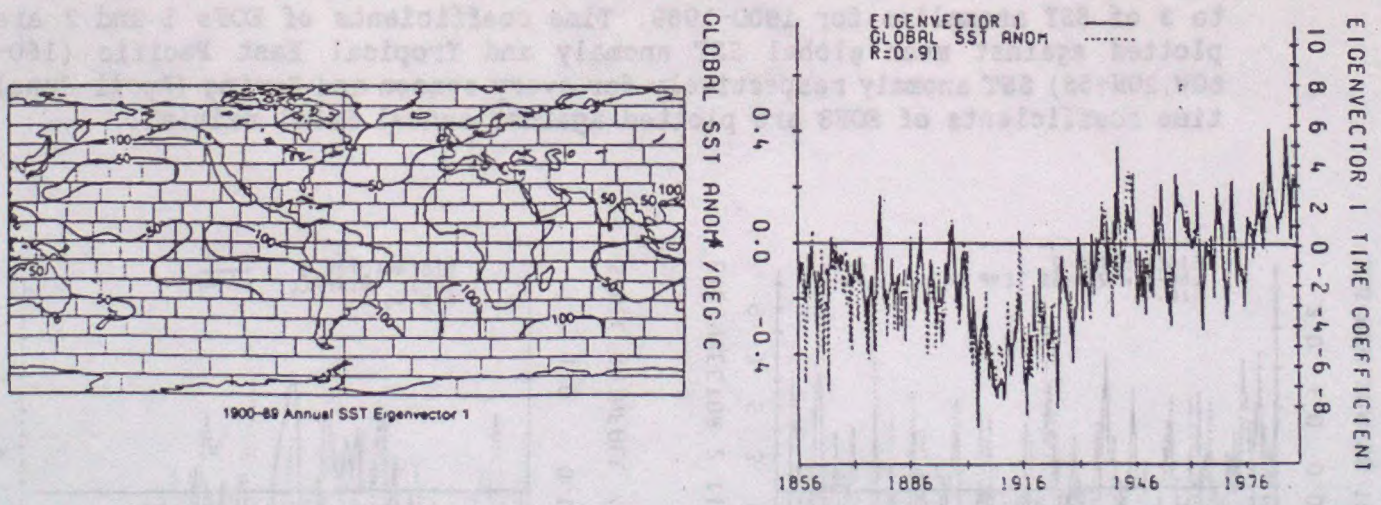
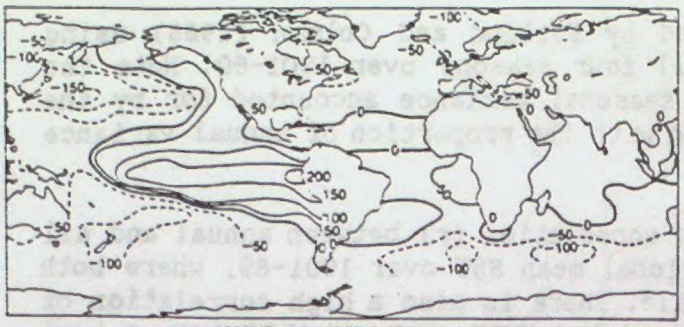


FIG 5a



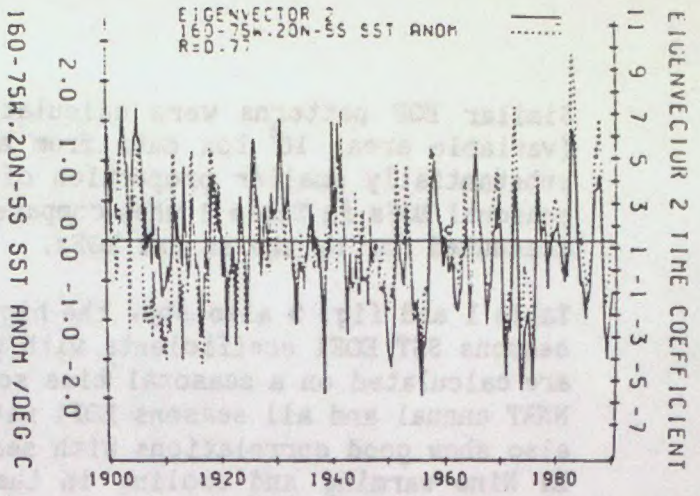
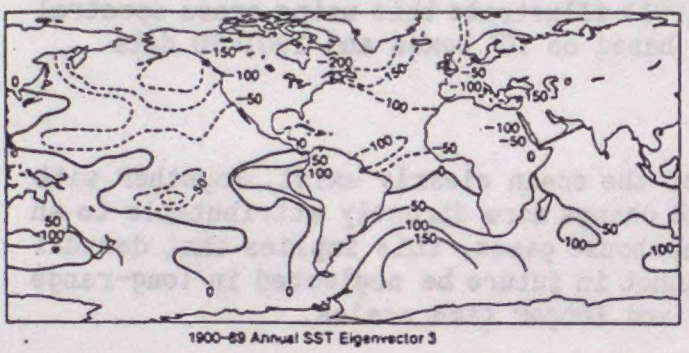


FIG 5b



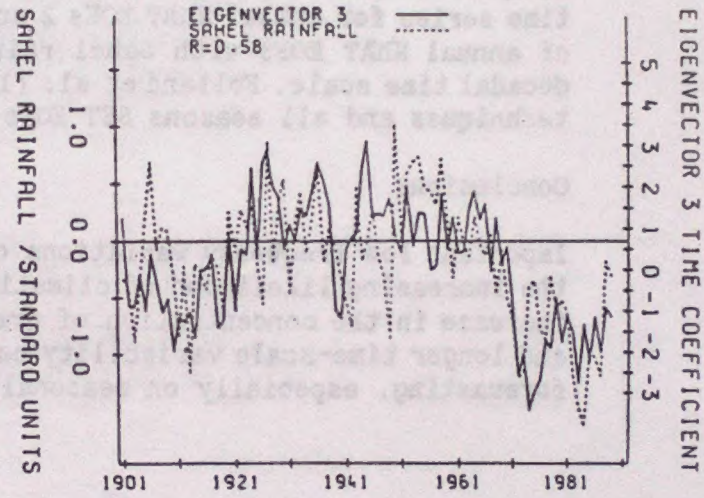
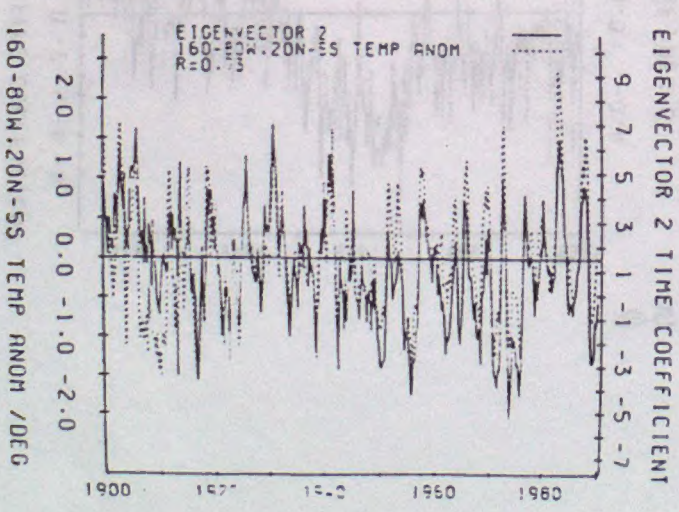


FIG 5c

Figs. 5a-5c Patterns and time series for individual seasons of annual EOFs 1 to 3 of SST anomalies for 1900-1989. Time coefficients of EOFs 1 and 2 are plotted against mean global SST anomaly and Tropical East Pacific (160-80W,20N-5S) SST anomaly respectively for every season and Spring (April-June) time coefficients of EOF3 are plotted against annual Sahel rainfall.



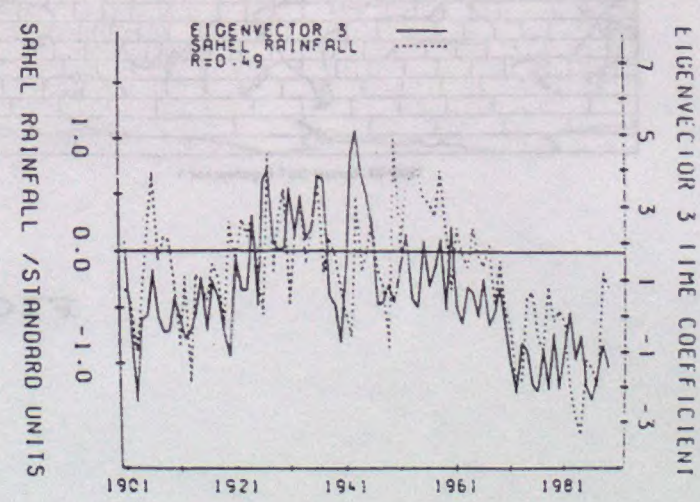


Fig. 6 Time series for annual NMAT anomaly EOF2 plotted against Tropical East Pacific SST anomaly for every season 1900-89 and Spring time coefficients of EOF3 plotted against annual Sahel rainfall.

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